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# A synthetic view of acceptance and engagement with smart meters in the United States

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ABSTRACT

Smart meters are a crucial infrastructural feature of a modernizing grid. Smart meters enable dynamic rate structures, a wide range of smart home technologies, energy use feedback, and greater use of distributed renewable energy. Yet, ratepayers are often unfamiliar with smart meters and their benefits, have ambivalent or negative attitudes toward them, and may outright oppose their use. Past research has identified numerous factors that influence acceptance and engagement. However, these factors are tested in isolation and only partially representative of the broader literature on energy technologies. In this study, we compare the relative effect of an expanded range of factors on smart meter acceptance and engagement. We use a survey (N = 609) of homeowners in Ithaca, New York who are part of an upcoming smart meter rollout. We find that, ceteris paribus, familiarity and climate change risk perceptions have the greatest effect on smart meter acceptance, while smart meter acceptance, age, and income have the strongest effect on engagement. Our findings have two primary implications: (1) outreach and communication should focus on increasing familiarity and demonstrating the climate benefits of smart meter enabled products and services; and (2) that outreach and communication is insufficient to increase uptake by all segments of the population.

## 1. Introduction

To reduce greenhouse gas (GHG) emissions and avoid the direst impacts of climate change, industrialized countries must achieve two goals: 1) transition to renewable generation technologies such as wind, solar, tidal, and geothermal energy; and 2) reduce total energy demand [1]. Each of these goals will require changes to the electrical grid [2]. The combination of new technologies needed are often referred to holistically as the "smart grid". One critical piece of any transition to a smart grid is to implement advanced metering infrastructure (AMI), such as so called 'smart meters', to manage electricity generation and distribution. Electric smart meters can be deployed for a wide range of functions that can lead to a reduction in GHG emissions. By sending detailed information about commercial and residential electricity use back to the utility, electricity production can be more efficiently managed, thus reducing total production [3]. Providing detailed information to property owners, often in conjunction with other smart home technologies, helps them to more efficiently use electricity [4–6]. Smart meters facilitate real-time pricing, which can reduce overall energy consumption [7]. Smart meters also facilitate distributed generation [8], thus creating further incentives for property owners to install renewable energy technology on site.

Given smart meters' potential role in reducing greenhouse gas emissions, an increasing amount of scholarly attention has been paid to them in recent years. Here we focus on the social science-based research on smart meter *acceptance* and *engagement.* By smart meter acceptance we refer to the degree that property owners are willing to have smart meters installed on their property and what they think and feel about it. By engagement we refer to the use of the products and services enabled by smart meters. We consider both, as merely accepting the installation of smart meters is not sufficient to see significant benefits. Ratepayers must be willing and able to engage in the kinds of behaviors that smart meters enable for significant benefits to accrue. Smart meters themselves do little to curb energy consumption; rather, they are merely vectors for behavioral change [9].

Social scientists have identified a number of barriers to smart meter acceptance and, to a lesser extent, engagement. These include trust in industry, familiarity, a sense of procedural fairness, and concerns related to privacy and cost. However, these studies tend to evaluate these factors in isolation, and as such, no synthesis has been done to evaluate which factors have the *greatest relative impact on acceptance and engagement*. Consequently, we compare the relative effect of factors predicted to impact smart meter acceptance and engagement. What's more, we expand on research on smart meters specifically by incorporating

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research from a wider range of energy technology studies that have heretofore been unincorporated into studies of smart meter acceptance and engagement. Simply, we do not know which factors have the *strongest and weakest* effect on acceptance and engagement, only that there are many factors that exhibit some effect. The summative contribution of this study, therefore, is to test an integrated and expanded model of smart meter acceptance and engagement that may assist policymakers and scholars in better designing smart meter programs to increase the GHG reducing effects of the technology.

## 2. Literature review

### *2.1. Social acceptance and engagement with energy technology*

In order for the benefits of smart meters to be realized, customers must be willing to accept this technology. Opposition to implementation, as is found in other forms of energy development [10], can slow or halt development altogether. In the case of smart meters, it may also lead to less engagement with the technology. While utilities and government have often assumed that high general support for certain energy technologies will lead to seamless implementation, this has not been the case [11]. Support for energy technologies within a community or by impacted consumers is typically referred to as "community acceptance" [11], which is defined as "the specific acceptance of siting decisions and renewable energy projects by local stakeholders, particularly residents and local authorities." (pg. 2685). Wolsink [12] points out that acceptance tends to follow a U-shaped curve, with acceptance high in the early phases of the project, declining during the siting process, and then increasing after implementation.

Evidence from previous rollouts suggests that the widespread implementation of smart meters is unlikely to be successful unless it adequately addresses the perspectives of consumers [13,14]. In Europe, notable controversies have occurred over mandatory rollouts of smart grid technology [15]. Though a more limited amount of research has been conducted on acceptance in the United States, in 2009, as part of the American Recovery and Reinvestment Act (ARRA), federal funds were poured into implementation of the smart grid [16], with 4.5 billion dollars coming directly from the ARRA, making issues of implementation directly relevant to the U.S. context. In a meta-analysis of 100 smart meter pilot programs containing almost 450,000 European consumers, a 2011 report by Empower Demand [17] concludes:

> "During piloting, there can be a technological focus or a preconceived opinion that the technology is what decides program success. Our findings challenge this focus. The main difference we found between pilot success and failure is the ability of the program designers to meet consumer needs through the demand side program. Meeting a need is the foundation of consumer engagement and thereby of a program's success. The technology is the enabler within this value chain." (pg. 62)

Opposition as a form of obstruction is not the only negative outcome of a smart meter rollout. The strongest climate change mitigation effects of smart meters require that homeowners engage with the technology and use the products and services it enables to reduce their energy consumption, including the use of smart home technologies, adapting to dynamic pricing, or using energy analysis tools that allow ratepayers to voluntarily adjust their own behavior. Compared to *acceptance*, far less research has considered the social psychological factors—that is, the non-economic factors—that shape *engagement* with the technologies and services that meters enable. This not only has implications for accessing the benefits of smart meters but may also play into the response to rollouts of the technology. As Goulden et al. [18] argue, "…smart grid designs must look beyond simply the technology and recognize that a smart user who is actively engaged with energy is critical to much of what is proposed by demand side management." (p.21) Simply, understanding the factors that influence whether and how ratepayers engage with smart meters after their installation is equally as critical as understanding the factors that shape their general acceptance of the technology's presence in their homes.

In the review that follows, we turn our attention to the factors that may influence customer technology acceptance and engagement. We review research that directly examines smart meter acceptance and engagement while also considering alternative factors that have yet to be applied to the topic. In doing so, we present eight hypotheses describing the relationship between social psychological factors and acceptance and engagement with smart meters.

#### *2.1.1. Privacy*

Some customers believe that smart meters lead to a loss of privacy by providing detailed information about household behaviors. As such, beliefs about how smart meters may expose consumers to violations of privacy are a critical factor in acceptance [19–21]. Quinn [22] identifies four types of privacy concerns related to smart meters: individual patterns, real-time surveillance, information detritus, and physical invasion. Individual pattern concerns refer to the ability of any person with the data to determine a person or household's general behavior based on, for instance, the use of appliances such as a hot water heater. Real-time surveillance concerns refer to the ability of a person or group to monitor behavior as it happens, either a utility or a person who has hacked into the network. Information detritus concerns refer to the sale of information to a third party. For instance, the utility could sell this information to other corporations or to law enforcement. This is not uncommon, as companies frequently sell business records, which in most cases in the United States are not covered under the fourth amendment of the constitution [16]. In the E.U., smart meter data is classified as personal data and therefore protected from resale [23]. Physical invasion concerns refer to the ability of anyone in control of real-time data to determine if a property is occupied for the purpose of illegal activity such as burglary or arson. Scholars have suggested that privacy concerns can be reduced by implementing "privacy friendly" alternatives, for instance by decreasing the granularity of the data collected by the smart meter [23].

Privacy concerns are directly linked to the issue of trust. Customers who do not believe that utilities can be trusted to secure their personal information are less likely to support smart meter implementation [15]. Therefore, we fold privacy concerns into procedural fairness concerns, as trust is a key component of procedural fairness, as we discuss below.

#### *2.1.2. Procedural and distributive fairness*

As has been demonstrated repeatedly, concerns over procedural fairness have a significant effect on the acceptance of energy infrastructure [24–26]. Procedural fairness generally refers to access or representation in decision-making processes and the power (or lack thereof) to influence them [26]. Colquitt and Rodell [27] define fairness as the "global perception of appropriateness" (p. 188), and it may include dimensions related to consistency [28,29], trust [30], respect [31,32], ability to influence the final agreement [33] and control [34].

One particular sub-characteristic of importance in perceptions of procedural fairness is trust. Trust is particularly important in situations where familiarity with a technology is low [35]. Trust in this case operates as a heuristic in the intuitive mode of information processing characteristic of dual-process theories [36]. It is also likely to influence perceptions of risks and benefits [37]. Research on social acceptance of carbon capture and storage technologies has found that local residents, lacking familiarity or interest in the project, tend to delegate responsibility to organizational actors (e.g. industry, government), particularly those who they trust [38]. Trust has been identified as a central factor in the technological transition to a smart grid technologies [19–21,39].

The perceived distribution of risks and benefits from smart meter technologies is likely to play a key role in the acceptance of this new technology, or what is often referred to as distributive fairness. Distributive fairness may be conceptualized as a balance in the risk and

benefit of the industrial process for directly affected populations or the equal distribution of risk and benefit broadly throughout society [40]. For new technologies such as smart meters, the perceived benefits of the technology may outweigh the perceived risks [41,42]. This occurs because individuals tend to attenuate their perception of risk for technologies they find to be beneficial [43]. Frewer et al. [44] have noted the importance of this inverse relationship between risk and benefit; influencing one tends to influence the other. Expectations of risk and benefit are likely to play key roles in social acceptance of smart meters.

Given that previous research has shown perceived procedural and distributive fairness lead to greater acceptance of energy technology, we propose the following hypotheses:

**H1.** *Greater perception of utility-specific procedural fairness is associated with greater acceptance of smart meters and higher likelihood of engaging in smart meter enabled behaviors.*

**H2.** *Greater perceptions of equal distribution of risks and benefits from smart meters between consumers and utilities is associated greater acceptance of smart meters and higher likelihood of engaging in smart meter enabled behaviors.*

### 2.1.3. Cost

The issue of cost for consumers influences smart energy technology acceptance in at least two documented ways. First, some customers fear that the installation of smart meters will increase the cost of energy [45]. In fact, two utilities have faced lawsuits alleging that they overcharged customers after the installation of smart meters [46]. Second, customers may have unrealistic expectations of immediate savings from smart meters [3]. While, as we previously noted, smart meters can reduce costs for utilities, immediate price reductions are unlikely to occur for most customers. Prices may reduce over time, but overly optimistic expectations about savings may lead to backlash after the installation of the technology. In fact, smart meters may increase cost for some consumers. The new meters are more accurate in measuring energy use, and because older electromechanical meters increasingly underestimate usage as they age, the new meters may cause a spike in consumer's energy bills [47]. Lineweber [48], in a survey of potential smart meter users in the U.S., finds that most users do not believe they will receive much financial benefit form widespread installation even if they support the technology generally. An online survey of British consumers found that those most concerned about price effects were less likely to accept a demand-response pricing structure based in the use of a smart meter [49]. Contrarily, and related to smart-home technologies generally, Balta-Ozkan et al. [50] found that "saving a few pence" is unlikely to be a strong motivator in adopting the technology.

To evaluate the relative effect of cost compared to the range of social psychological factors analyzed here, we utilize a measure of "price consciousness". This concept addresses the willingness of a consumer to change their behavior based on changes in the price of a product or service [51,52]. We particularly rely on the constructs developed by Alford and Biswas [53], which we tailor to the issue of energy consumption.

Overall, research on costs suggests that savings are not the primary issue in play in the social acceptance of smart meter technology but may still play a role. We expect that ratepayers who are more sensitive to price signals will be more likely to accept the technology, therefore we propose the following hypothesis:

**H3.** *Greater willingness to change energy use behavior due to changes in price is associated with greater acceptance of smart meters and higher likelihood of engaging in smart meter enabled behaviors.*

### 2.1.4. Climate change risk perceptions

In an aforementioned study on smart meter acceptance, Spence et al. [49] find that individuals with greater climate change risk perceptions are more likely to accept the technology, and this effect on acceptance was stronger than that of cost. This is consistent with research that has demonstrated the importance of climate change risk perceptions in shaping support for climate change-related behaviors [54,55]. Given that respondents may associate smart meters with climate change and GHG reduction, we hypothesize that individuals with greater climate change risk perception will be more likely to accept and engage with smart meters. Operationally, we utilize the climate change risk perception metrics developed by Kahan et al. [56].

**H4.** *Greater perceptions of climate change risk is associated with greater acceptance of smart meters and higher likelihood of engaging in smart meter enabled behaviors.*

Similarly, we also explore support for traditional versus renewable energy sources. While possibly correlated with climate change risk perceptions, support for divergent energy types may be directly related to the acceptance of smart meters: smart meters enable increased usage of distributed energy, e.g. residential solar. As such, we expect that individuals who exhibit greater support for renewable energy will also exhibit greater acceptance of smart meters.

**H5.** *Greater support for renewable energy sources is associated with greater acceptance of smart meters and higher likelihood of engaging in smart meter enabled behaviors.*

### 2.1.5. Familiarity

In a study involving 22 in-depth interviews, Krishnamurti et al. [3] found that 20 of the 22 participants mistook smart meters for in-home displays and thermostats typically, which are smart home features enabled by smart meters but are not smart meters themselves. Therefore, the benefits they associated with smart meters (real-time energy use feedback) were not actually associated with the smart meter, but rather the additional technology they would need to purchase. Despite low familiarity, many of these participants wished to have smart meters installed on their property, although this desire was based on inaccurate and unfounded beliefs about smart meters [3]. The Boston Consulting Group found that, in 2010, only 15% of Americans reported being "very aware" of smart meters. This number is possibly inflated given the research by Krishnamurti et al. [3], which suggests that even those who believe they are aware hold multiple misconceptions. Yet, familiarity is particularly important for the understanding of risks and benefits of a new technology. Given that risks that are unknown tend to engender opposition [41], we suspect that greater familiarity will be associated with greater acceptance. As such, we propose the following hypothesis:

**H6.** *Greater familiarity with smart meters is associated with greater acceptance of smart meters and higher likelihood of engaging in smart meter enabled behaviors.*

### 2.1.6. Environmental concern

While never directly tested against smart meters, environmental concern has been shown to influence attitudes toward home energy saving measures in alternative contexts [57,58]. Poortinga et al. [59] demonstrate that environmental concern is one of the strongest indicators of willingness to accept home and transport energy saving measures. Environmental concern is also tied to support for general policy initiatives. Given the conceptual proximity of smart meters to general energy saving measures, we suspect that a similar relationship may be observed here, resulting in the following hypothesis. Like Poortinga et al. [59], we operationalize environmental concern through the use of the New Environmental Paradigm scale [60,61].

**H7.** *Greater environmental concern is associated with greater acceptance of smart meters and higher likelihood of engaging in smart meter enabled behaviors.*

#### 2.1.7. Acceptance and engagement as attitudes and behavioral intention

We finally examine the impact of acceptance itself on engagement. Thus far we have hypothesized that the same factors influencing acceptance will also have a direct relationship to engagement. Research on attitude and behavior, parallel concepts to acceptance and engagement, posits that attitudes toward a given object are the strongest predictor of behavioral intentions related to that object [62,63]. Thus, we would expect that overall attitudes (acceptance) directly predict behavioral intention (engagement) and attenuate the effects of the remaining factors.

**H8.** *Greater acceptance of smart meters is associated with greater intention to engage in smart meter-related behaviors.*

### 2.2. Summary and research objective

The disparate literature outlined above suggests a range of potential factors that may influence acceptance and engagement with smart meters. However, this range of factors has never been tested together in order to assess the relative strength of effects. This has produced a limited, non-synthetic understanding of the factors that influence acceptance and engagement. In response, a comprehensive comparison is needed to synthesize current research in order to better understand how smart meters can be accepted and used. Therefore, we integrate the factors discussed in our literature review and apply them to both acceptance and engagement with smart meters.

## 3. Methods

This study involved a survey of homeowners in Ithaca, New York. These homeowners are part of the regional utility company's "Energy Smart Community" and its "Grid Upgrade Area", meaning that in mid-2017 residents living in this testbed had smart meters installed on their homes. *Prior* to the smart meter rollout, we implemented a four-wave mail survey with a random sample of 2000 homeowners in the rollout footprint. The sample was provided by the regional utility. The four-wave approach involved first sending a copy of the survey with a cover letter, followed by a reminder one week later, followed by a reminder and an additional copy of the survey a week after that, and then a final reminder one week after that. A total of 609 homeowners completed the survey, for a response rate of 30.5%. We tested for non-respondent bias by conducting a telephone survey of non-respondents using a subset of critical variables. Analysis of the non-respondent data indicated no meaningful differences between the two samples, suggesting that our respondents are representative of the original sampling frame. The full mail survey took approximately ten minutes to complete and no incentives were offered for completion.

The sample is more educated, liberal, and wealthier than the national average, but was reflective of the local sampling frame (a small University town). A total of 83.4% of respondents indicate having at least a bachelor's degree; 57.2% indicate being very or somewhat liberal, while 17.4% indicate being somewhat or very conservative; and 49.7% of respondents report earning over $100,000 dollars annually. Finally, our respondents were more likely to be male (55.7% male versus 41.7% female), white (83.9% white), and had a mean household size of 2.48. We include covariates for income and education in our models to control for their effect.

Our analysis reports on results from the survey questions listed in Table 1. Our first outcome variable—acceptance of smart meters—is listed first. Table 3 describes our behavioral engagement dependent variable. The remaining rows are occupied by explanatory variables, including measures of familiarity, climate change risk perceptions, environmental concern, procedural and distributive fairness, support for traditional and renewable energy sources, and price consciousness. See Table 1 for all question wording, descriptive statistics of explanatory variables, and factor and reliability analysis. We include several covariates in addition to our explanatory variables. These are described in Table 2.

For all reliability analyses, coefficients ranged from 0.428 to 0.929. Several items, designated by an asterisk, were removed due to improvement in the overall reliability of the measure and the low coefficient value. Composite values were then computed for the remaining items within each measure, with Cronbach Alpha values ranging from 0.673 to 0.951.

## 4. Results

### 4.1. Descriptive analysis

We begin by describing the distribution of our outcome variables: acceptance and engagement. The Cronbach's Alpha for the single factor encompassing all acceptance items was 0.931. Respondents generally present positive responses across the items, with a mean value of 3.71 on a scale of 1-5. "Neutral" refers to those respondents who averaged exactly 3.0 in the composite metric. Accepting responses are > 3.0, while rejecting responses are < 3.0. In total, 78.8% of respondents exhibited accepting responses, 13.4% of respondents exhibited rejecting responses, and a remaining 8.8% exhibited a neutral response.

Table 3 describes engagement for the three categories of behavior examined in our research. For each behavior, respondents were given a brief description of what was meant by the label. Smart home technologies were described as, "e.g. washer and dryer that turn on automatically when energy demand is low."; dynamic pricing was described as, "billing that charges you more when demand is high and less when demand is low, varying by time of day."; and energy analysis tools were described as, "detailed data about your home energy use, allowing you to monitor and adapt how you use energy." For smart home technologies and time of use pricing, a plurality of respondents indicated that they might use either, with 20.4% indicating they would definitely use smart home technologies and 26% indicating they would definitely adjust behavior based on time of use pricing. The services most likely to be used are energy analysis tools, with 46.8% indicating they would definitely use them. Overall respondents are generally accepting of smart meters and large majorities might or will use their enabled products or services.

### 4.2. Factors associated with acceptance

What factors are associated with acceptance of smart meters? To answer this question, we conducted an ordinary least squares regression[1] on the composite acceptance measure described in Table 1. Several factors explain variation in smart meter acceptance (Table 4). The factor with the strongest association, as indicated by the standardized estimate, is familiarity. Individuals who perceive themselves as more familiar with smart meters tend to be more likely to accept them. The second strongest association is climate change risk perception. The greater risk an individual perceives from climate change, the more likely they are to accept smart meters. The third strongest association is price consciousness. The more willing an individual is to change their energy use behavior to save money the more likely they are to accept smart meters. The fourth strongest association is related to perceptions of distributive fairness. The more an individual perceives that the risks and benefits of smart meters are equally distributed, the more accepting they are of smart meters. The fifth strongest association is support for renewable energy technologies. The greater support an individual has

[1] For all of the ensuing models, none of the variance inflation factors exceeded 2.5, which suggests that the selected explanatory variables do not create problems of multicollinearity ([66] [67];). However, political orientation and trust were dropped from our analysis due to their high correlation (r > .6) with climate change risk perceptions and procedural fairness, respectively.

**Table 1**
Explanatory and dependent variables.

| | Mean | Item total correlation | α if item deleted | α |
|---|---|---|---|---|
| Acceptance[a] | | | | .942 |
| A smart meter would benefit me and/or my family | 3.73 | .831 | .919 | |
| Smart meters would benefit my community | 3.81 | .828 | .919 | |
| Smart meters would benefit the environment | 4.00 | .805 | .920 | |
| Smart meters are an important part of our future energy system | 3.90 | .838 | .918 | |
| I would be excited to have a smart meter in my home | 3.55 | .832 | .918 | |
| I would be nervous to have a smart meter in my home[b] | 3.52 | .475* | .942 | |
| A smart meter would allow me to change my/my family's behavior in a positive way | 3.60 | .750 | .923 | |
| I would choose to not participate in a smart meter program[b] | 3.87 | .736 | .924 | |
| I would encourage others to have a smart meter in their home | 3.42 | .704 | .926 | |
| Familiarity[a] | | | | .949 |
| How a smart meter would affect my electricity bill | 3.07 | .891 | .931 | |
| How a smart meter would benefit my electric utility | 3.22 | .845 | .940 | |
| How my household would benefit from a smart meter | 3.15 | .870 | .935 | |
| How my electric utility would use the data from the smart meter | 3.02 | .825 | .943 | |
| How I would use a smart meter | 2.97 | .869 | .935 | |
| Environmental concern (NEP)[a] | | | | .750 |
| Most environmental problems can be solved by applying more and better technology[b] | 2.29 | .091* | .750 | |
| Plants and animals exist primarily to be used by humans[b] | 4.02 | .392* | .664 | |
| The balance of nature is very delicate and easily upset by human activities | 4.28 | .530 | .622 | |
| Ecological, rather than economic, factors must guide our use of natural resources | 3.96 | .586 | .597 | |
| We attach too much importance to economic measures of the well-being of society | 3.68 | .428 | .652 | |
| When humans interfere with nature, it often produces disastrous consequences | 3.94 | .567 | .605 | |
| Procedural fairness[a] | | | | .889 |
| My utility respects its customers | 3.27 | .795 | .851 | |
| My utility is transparent | 2.92 | .749 | .859 | |
| My utility can be trusted to act in good faith | 3.01 | .785 | .852 | |
| My utility listens to customers who express their views | 3.00 | .771 | .858 | |
| My utility treats every customer the same way* | 3.05 | .545 | .889 | |
| Customers can influence outcomes of interactions with my utility | 2.97 | .577 | .886 | |
| Distributive fairness[a] | | | | .910 |
| The risks of smart meters would be equally distributed between customers and my utility | 2.84 | .836 | – | |
| The benefits of smart meters would be equally distributed between customers and my utility | 2.88 | .836 | – | |
| Price consciousness[a] | | | | .895 |
| I am not willing to go to extra effort to save money on my electricity bill[b] | 3.83 | .111* | .895 | |
| I would change my behavior to lower my electricity bill | 3.89 | .585 | .236 | |
| The money saved by changing my energy use is worth the time and effort | 3.80 | .635 | .114 | |
| Climate change risk perceptions[c] | | | | .951 |
| Human health | 5.60 | .914 | .926 | |
| Human safety | 5.53 | .929 | .921 | |
| Economic prosperity | 5.35 | .840 | .949 | |
| The environment | 6.06 | .848 | .946 | |
| Support for renewable energy sources[d] | | | | .673 |
| Solar | 4.47 | .518 | .595 | |
| Wind | 4.60 | .465 | .603 | |
| Hydropower | 4.45 | .440 | .620 | |
| Bioenergy | 4.19 | .463 | .615 | |
| Support for non-renewable energy sources[d] | | | | .859 |
| Oil | 2.45 | .760 | .780 | |
| Conventional natural gas | 3.38 | .625 | .817 | |
| Natural gas from shale | 2.24 | .728 | .788 | |
| Nuclear* | 2.78 | .478 | .859 | |
| Coal | 1.98 | .676 | .804 | |

[a] Response options: strongly agree (5); slight agree; neither (3); slightly disagree; strongly disagree (1).
[b] Reverse coded to align with orientation of other questions.
[c] Response options: 1–7, where 1 = no risk, 4 = some risk, 7 = great risk.
[d] Response options: strongly support (5); slightly support; neither (3); slightly oppose; strongly oppose (1).
* Dropped from composite factor due to alpha if deleted value.

for renewables, the more likely they are to accept smart meters. Overall, this model explains a large proportion of variance in the data, with an adjusted $R^2$ of 0.413.

### 4.3. Factors associated behavioral engagement

Regarding behavioral engagement, we look at each potential behavior individually. The use of smart-home technologies, energy analysis tools, and willingness to adapt to time of use pricing all represent unique behavioral contexts, and therefore the factors which influence behavioral engagement may vary. We use an ordinal logistic regression, as the dependent variables each have ordered, categorical response options (see Table 5 for full results).

What is consistent across the models are the effects of age and acceptance. Acceptance of smart meters has by far the greatest effect on behavioral intention for each behavior. However, we find that, independent of acceptance, older respondents are more likely to adjust to time of use pricing and less likely to use smart home technologies and energy analysis tools, ceteris paribus. For smart home technology, we also find that income is associated with behavioral engagement. Individuals more familiar with smart meters are more likely to use smart home technologies, while households with lower income are less

**Table 2**
Sociodemographic covariates.

| Education | |
|---|---|
| "Please indicate the highest degree of education you have attained" | Less than high school diploma = .8%<br>High school diploma = 4.9%<br>Some college = 10.9%<br>College degree = 29.9%<br>Graduate degree = 53.5% |
| Gender | |
| "What is your gender?" | Male = 55.6%<br>Female = 41.9%<br>Other[a] = 2.5% |
| Political orientation | |
| "In general, do you think of yourself as…" | Very liberal = 24.5%<br>Somewhat liberal = 32.6%<br>Moderate/middle of the road = 25.4%<br>Somewhat conservative = 12.6%<br>Very conservative = 4.8% |
| Household income | |
| What was the total combined income (before taxes) of all members of your household in 20[1]6? (Please include money from jobs, net income from business, farm or rent, pensions, dividends, welfare, social security payments and any other money income received by you or any other family member.) | $0-9999 = .4%<br>$10,000-14,999 = .9%<br>$15,000-24,999 = 5.3%<br>$25,000-49,999 = 12.5%<br>$50,000-74,999 = 15.2%<br>$75,000-99,999 = 15.9%<br>$100,000-149,999 = 24.1%<br>$150,000+ = 25.6% |
| Age | |
| "In what year were you born"[b] | Mean = 59 years |

[a] Dropped due to low number of observations.
[b] Converted into age by subtracting year given from 2017.

**Table 3**
Behavioral engagement with enabled products and services.

| | Would not use | Unlikely to use | Might use | Definitely would use |
|---|---|---|---|---|
| Smart home technology | 15.8 | 24.5 | 39.4 | 20.4 |
| Dynamic pricing | 8.2 | 16.8 | 49.0 | 26.0 |
| Energy analysis tools | 6.6 | 8.0 | 38.6 | 46.8 |

**Table 4**
Smart meter attitudes.

| Variable | β (SE) |
|---|---|
| Familiarity | 0.35 (.03)*** |
| Procedural fairness | −0.02 (.04) |
| Distributive fairness | 0.18 (.04)*** |
| Environmental concern | −0.01 (.05) |
| Climate change risk perception | 0.25 (.03)*** |
| Price consciousness | 0.21 (.03)*** |
| Support/renewable energy | 0.13 (.06)** |
| Education | 0.07 (.04) |
| Gender (female) | 0.01 (.07) |
| Household income | 0.03 (.02) |
| Age | 0.07 (.01) |
| Adjusted $R^2$ | .413 |

*p < .05; ** p < .01; *** p < .001.

likely to use smart home technologies. Regarding dynamic pricing, we additionally find that individuals with greater environmental concern are less likely to engage with time of use pricing and that those who tend to perceive their utility as generally operating in a procedurally fair manner are less likely to accept dynamic pricing. These models explain a modest proportion of the variance in the data, with pseudo-$R^2$ ranging from .228 to .268.

## 5. Discussion

This study sought a single objective: to compare the *magnitude* and *relative effect* of various explanatory factors on acceptance of and engagement with smart meters. What we find suggests that homeowners tap into several factors when evaluating whether to accept or reject smart meters in their home. The strongest factor, as measured by standardized coefficients, is familiarity (hypothesis #6). Those who indicate greater familiarity are more like to indicate acceptance. This is a positive indication for utilities and government agencies pushing expansion of the technology, suggesting that as individuals become more familiar they will be more likely to accept the technology. However, research is needed to track this change over time to confirm this hypothesis.

Several factors not directly related to smart meters had a significant effect on acceptance net of familiarity, suggesting that homeowners are associating the meters with specific issues in order to evaluate them. The most impactful of these associated factors is climate change risk perceptions (hypothesis #4): smart meter associated technology seems to be perceived as a potential hedge against climate change. Perhaps relatedly, homeowners who are more likely to support renewable energy sources are also more likely to report acceptance (hypothesis #5). Taken together, we may interpret this as homeowners anticipating the potential impacts of smart meters on a broader energy transition. This is also a potential point of emphasis for targeted communication and engagement. Linking smart meters to climate change and renewable energy may produce more positive attitudes for those who believe in climate change. Of course, such a message may also produce more negative attitudes for those who do *not* believe in anthropogenic climate change [64]. These findings, taken together, suggest a broad base of cognitive support for smart meter attitudes. Outreach and communication campaigns that solely focus on, for instance, price, may ultimately fail to capitalize on other factors that influence acceptance. While savings can and should remain a part of a broad communication strategy, our research shows that other factors are more likely to engender positive attitudes.

This study also partially supports previous qualitative research that has argued that issues of procedural and distributive fairness impact local opposition to smart meter rollouts. Indicators of distributive fairness exhibited an independent effect on smart meter acceptance (hypothesis #2). However, procedural fairness related to the utility did not (hypothesis #1). Procedural issues may become more important over time as a rollout occurs and/or the installation of smart meters becomes intrusive for homeowners, given that, unlike the distribution of risks and benefits, this element is unknown prior to the rollout. Finally, price consciousness had a positive relationship with acceptance: the more willing a homeowner is to change their behavior to save money the more likely they are to indicate acceptance of smart meters (hypothesis #3). This confirms research that has emphasized the importance of cost concerns. Regarding environmental concern (hypothesis #7), we do not observe any statistically significant effect on acceptance.

Regarding behavioral engagement with three distinct smart meter-enabled products and services, we find divergent results. Few of the social psychological constructs measured, outside of smart meter acceptance itself, impact engagement. However, this is consistent with standard models of behavioral intention, which argue that attitudinal constructs such as acceptance have the most direct relationship to behavior, thus confirming our eighth and final hypothesis. While our social psychological factors minimally impact engagement, two sociodemographic conditions exhibit stronger and more consistent effects. For smart home technologies, one of the highest impact behaviors homeowners can engage in to reduce their carbon footprint, we find that income has a significant effect on intention to use smart home technologies. This should not be a surprise, as smart home technologies

**Table 5**
Behavioral intentions[a].

| | Smart home technology | Time of use pricing | Energy analysis tools |
|---|---|---|---|
| Variable | β (SE) | β (SE) | β (SE) |
| Smart meter attitudes | 1.03 (.14)*** | 0.94 (.14)*** | 1.07 (.14)*** |
| Familiarity | −0.19 (.11) | 0.08 (.11) | −0.10 (.12) |
| Procedural fairness | −0.13 (.11) | −0.26 (.11)* | −0.11 (.11) |
| Distributive fairness | 0.03 (.11) | 0.17 (.17) | −0.13 (.12) |
| Environmental concern | −0.11 (.13) | −0.28 (.13)* | −0.26 (.14) |
| Climate change risk perception | −0.16 (.13) | 0.26 (.13) | 0.08 (.14) |
| Price consciousness | 0.02 (.10) | 0.11 (.11) | 0.18 (.11) |
| Support/renewable energy | −0.04 (.10) | −0.09 (.11) | −0.03 (.11) |
| Education | 0.01 (.10) | 0.06 (.11) | −0.03 (.11) |
| Gender (female) | 0.18 (.10) | 0.16 (.10) | 0.16 (.11) |
| Household income | 0.25 (.10)* | 0.03 (.11) | 0.12 (.11) |
| Age | −0.19 (.09)* | 0.35 (.10)*** | −0.26 (.10)** |
| N | 435 | 434 | 435 |
| Nagelkerke $R^2$ | .228 | .267 | .268 |

*p < .05; ** p < .01; *** p < .001.

[a] All independent variables were standardized before analysis to allow us to examine relative effect on our dependent variables. Each model uses an ordinal logistic regression. Table reports parameter estimates and, in parentheses, standard errors.

often require large capital inputs that many families cannot afford. At the very least, this finding suggests that many ratepayers believe that smart home technologies are not financially accessible.

What is surprising is that one of the covariates—age—appears to have a significant effect on engagement, but in varying ways. For the use of smart home technologies and energy analysis tools the relationship is negative. Older homeowners are less likely use these products/services. This may be due to the nature of the technology: both require knowledge and familiarity not only with smart meters, but with other advanced digital technologies. Older homeowners may come to feel that they do not benefit, therefore, from this new technology and the behavioral opportunities it presents. However, regarding time of use pricing, older respondents appear to be *more* likely to change their behavior. This may be due to having a more flexible schedule (e.g. retirees), though this is speculative. Therefore, the behavioral benefit of smart meters is not null for older homeowners, but rather, varies between the types of opportunities they present.

Our findings regarding age and income raise a considerable challenge to research on smart meter acceptance and engagement. While past research has emphasized the social psychological factors that influence acceptance and engagement, we find that social *structural* factors may play a critical role in facilitating household adaptation to the technology and the system changes that will follow. Recent research has noted that system-wide energy transitions may produce an unequal distribution of risks and benefits across social groups (Carley et al. 2018; Jenkins et al. 2016). Dynamic pricing is one such system-wide transition, with states such as California transitioning to default enrollment of consumers into dynamic rate structures. As we observe here, however, poorer and older households may be left behind in this transition, as they anticipate not being able to adjust behaviorally and may ultimately be penalized the new rate structures. Future research should give greater consideration to social structural factors not examined here, including housing type (homes versus apartments), property ownership (owned versus rented), and race, to name but a few.

Lastly, we find two apparently confounding, statistically significant effects of environmental concern and procedural fairness on willingness to accept time of use pricing. The negative association between procedural fairness and willingness to accept time of use pricing may be reflective of how residents view time of use pricing. Those who tend to see their utility as operating in a fair way may view time of use pricing specifically as a violation of that standard. The findings related to environmental concern may at first appear surprising, but they are likely reflective of the nature of the New Environmental Paradigm (NEP) scale utilized here. The NEP contrasts beliefs in the protection of ecological resources with the belief in the ability and value of economic systems to address human needs. As such, a negative relationship here may reflect a belief in the ability of changes in the economic system (i.e. price signaling) to achieve a given end (e.g. GHG emissions reduction, behavior change, etc.).

The key limitation of this study relates to its sample. This is arguably a “best case” scenario for a smart meter rollout: a liberal, educated, wealthy population open to an alternative energy future. As such, the degree that these findings are generalizable to the American population is possibly limited. That said, in controlling for income and education, we do find that these factors have little effect on acceptance and only income has an effect on one of the three examined behaviors. In that light, our findings related to income become especially critical. In areas where a larger proportion of the population is poor or working class, the benefits of smart meters for home owners will be attenuated. What’s more, for renters, the benefits may be even more deeply attenuated due to income constraints. Regardless, although smart meter rollout would likely differ across sites, future research should test this model on a nationally representative sample—or at minimum, in a variety of contexts—to validate our findings.

The policy implications of this work are clear and two-fold. First, in order for smart meters to produce the benefits that policymakers and utilities seek, ratepayers must actively engage with the technology (Hoenkamp et al., 2011). Our research shows that one way to achieve this is to promote the technology and create more positive attitudes about them. This can be done, as we show, be emphasizing the emissions reducing potential they offer, their implications for renewable energy, and to ensure and communicate an equitable distribution of risk and benefit between ratepayers and their utility. Violations of this latter issue may, for instance, involve passing the cost of smart meters onto the ratepayer. Most of all, we find that simply creating greater familiarity with a technology that is known to be poorly understood will engender more positive attitudes and lead to greater engagement.

However, we also find that any attempt to promote smart meters will inevitably come up against structural barriers not likely to be resolved by outreach and marketing. Utilities, public service commissions, and policymakers should consider broader structural efforts to protect vulnerable groups from negative impacts and to seek structural approaches to increasing engagement. For instance, this could include subsidizing the cost of specific smart home technologies that allow all households to access the benefits of smart meters. We also find that older ratepayers may be less likely to adjust to technology-dependent behaviors, including the use of smart home technologies and energy analysis tools. Utilities should consider ways to better engage this population which can be marginalized by technological change. Lowering

the barriers for behavior change for these large subpopulations will not only produce a more egalitarian technological transition, but will also increase the benefits of smart meters and their associated technologies. Our findings related to social structural barriers echoes recent research that has questioned the degree to which informational programs can significantly motivate behavior change for different social groups [65]. Advocates for smart energy transitions may need to consider first and foremost efforts that target structural disadvantage rather than informational or attitudinal variation if they wish to promote the benefits of smart energy technologies and services.

## 6. Conclusion

This study demonstrates the relative effect of a wide range of factors on smart meter acceptance and engagement. We find that familiarity and climate change risk perceptions have the strongest effect on acceptance, while acceptance, age, and income have the greatest effect on engagement. Our findings have two principal implications. First, utilities should double down on efforts to increase familiarity of smart meters and their enabled products and services, and in doing so emphasize the potential climate change benefits of the technology. Second, future research should investigate how utilities and policymakers can insulate vulnerable groups from risk imposed by smart meter-enabled changes to energy distribution while encouraging a more equitable distribution of benefits.

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